Seismic strengthening of RC beams by internal partially bonded pre-stressing steel strands

Helisa Muhaj
Universidade NOVA de Lisboa
Supervisors: Carla Marchão, Válter Lúcio, Rita Gião

Department of Civil Engineering
Caparica, March 7, 2018
Seismic strengthening of existing RC beams

- Existing buildings designed according to existing old Codes
- Continuing development of the existing Codes
- Lack of structural details
- Unproperly detailing of plastic hinges regions
- Extension of the design working life
- Change of destination of the existing buildings
- Construction errors

Eurocode EN 1998-1:2004

- The ductile behaviour of structures under seismic actions is **largely dependent** on the behaviour of its **critical regions**.
- Critical regions details depend on the level of ductility required in the project.

Seismic strengthening of RC beams
New Zealand Code

New Zealand Code, NZC 1170.5:2004

- Critical regions strain does not depend on the level of ductility required in the project.
- Plastic hinges are grouped as reversing and unidirectional.
- Formation of plastic hinges depends on:
  - Gravity load
  - Shear and moment induced by gravity load vs shear and moment induced by seismic action
  - Span length
  - Section strength and reinforcing details

Fenwick R.C. "Ductility demand for uni-directional and reversing plastic hinges in ductile moment resisting frames"
The loading protocol and research objectives

**Introduction**

- Innovative test procedure: cyclic and gravity load
- Experimental test of RC beam CB1
- Numerical model of specimen CB1 in ATENA Engineering 3D
- Numerical model of prestressed specimens: VRD1, VRD2, VRC1 and VRC2
- Comparison of experimental and numerical results
- Comparison failure mode observed in the reference beam (CB1) with the numerical strengthened beams (VRD1, VRD2, VRC1 and VRC2)

**Objectives:**

- Validate the test procedure for various failure modes
- Exploitation of the critical regions on beams by taking into account the gravity load
- Validate numerically the experimental results
- Estimate numerically the strengthened specimen load capacity

A typical cyclic loading test procedure
Test procedure
Cyclic loading including gravity load

Test procedure (Gião et al.):

i. (DC) Imposition of a pre-established displacement (+Δ);

ii. (FC) Unloading until the value of the gravity load is re-established;

iii. (DC) Imposition of a pre-established displacement-controlled unloading (-Δ);

iv. (FC) Loading until the value of the gravity load is re-established.

FC – force controlled
DC – displacement controlled
Test setup
Instrumentation of specimens CB1

Actuator

Reaction wall

Tension compression load cell CS-24-500kN

Rod-end

strong floor
H=0.8m

LVDT
Specimen CB1 (reference specimen)
Geometry and reinforcing details

Reinforcement details of the specimens

<table>
<thead>
<tr>
<th>Beam</th>
<th>Rect. beam reinf.</th>
<th>Slab reinforcement</th>
<th>T-beam reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. bars</td>
<td>area (m²)</td>
<td>ratio (%)</td>
</tr>
<tr>
<td>CB1</td>
<td>6ϕ12</td>
<td>0.00068</td>
<td>0.68%</td>
</tr>
</tbody>
</table>
Materials characterisation
Reinforcement and concrete

Reinforcing steel bars:
• Tensile test

Concrete tests:
• Modulus of Elasticity testing
• Splitting tensile strength test
• Compression test

Mechanical properties of the materials

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Concrete characteristics</th>
<th>Steel characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f_{cm}$ (MPa)</td>
<td>$f_{ctm}$ (MPa)</td>
</tr>
<tr>
<td>CB1</td>
<td>25.20</td>
<td>2.50</td>
</tr>
</tbody>
</table>
Specimen CB1
Failure mode and experimental results

- Failure of top rebars (tension)
- Moderate crushing of concrete
Numerical model of specimen CB1
ATENA Engineering 3D

15479 3D finite elements

3D reinforcing bars geometry
Specimen CB1
Comparison of the numerical and the experimental results

Cracks pattern and strain distribution

- CB1-Experimental Backbone Curve
- CB1-Atena 3D Backbone Curve
- 85\% of maximum load

Force (kN)
Moment (kNm)
Displacement (mm)
Drift (%)
Strengthening by partially bonded internal steel strands
Applying of the prestress force and injection of epoxy resin

A) Drilling the holes
- 2 parallel holes, D=18mm
- Drilling machine: Hilti DD-150-U
- Diamond core bits: DD/Bi 18/320(1000/1750/2500)

B) Applying the pretensioning force
- 2 parallel pretensioning steel strands, D_{nom}=15.7mm

C) Injection of the epoxy resin
- Hilti epoxy resin injection
- Hit-re 500 v3, L=500mm
- Unbonded pretensioning steel strands

D) Experimental loading
- ±Δ
- F₆

Department of Civil Engineering
Strengthening of specimen CB2
Preparation
Strengthening by bonding
Important factors and preparation of the specimens

Factors influencing bonding:

• Adhesive characteristics (HIT-RE 500 v3)
• Test setup (confined/unconfined test setup)
• Hole diameter (10-25% larger than strand/threaded rod/reinforcement diameter)
• Type of the drilling bit (diamond core)
• Edge distance and its ratio to the embedment depth
• Type of anchor (strand)
• Embedment depth
• Hole cleanliness
• Hole dump water
• Hole standing water
• Single vs. group anchor
• Air bubbles
• Reinforcement
• Temperature
• Humidity

Detailed preparation steps:

• Drilling the hole
• Let it dry (for the diamond core drilling bit the drilling process is with water)
• Cleaning of the hole
• Cleaning of the strand
• Injection of the resin
• Unloading
• Applying of the cyclic and gravity load test procedure
Experimental models of prestressed specimens
Specimens VRD1, VRD2, VRC1 and VRC2
Experimental models of prestressed specimens
Master Thesis of Gabriel Alves

Specimen VRD1

Specimen VRD2
Experimental models of prestressed specimens
Master Thesis of Gabriel Alves

Specimen VRC1

Specimen VRC2
Conclusions
Gravity load and the advantages of the proposed strengthening method

Testing procedure including gravity loading:

• Leads to more realistic failure modes than the conventional testing procedures.
• Gravity load effects are essential for assessing the plastic hinge formation.
• These tests predict reliably plastic hinges formation in the beam (reversible/unidirectional)
Conclusions
Gravity load and the advantages of the proposed strengthening method

Advantages of the proposed seismic strengthening:

- Increased load capacity
- Increased first crack load
- Increased yielding load
- Decreased residual deformations
- Enhanced energy dissipated
- Maintain existing permanent loads as before intervention
- No concentration of stresses near the anchorage regions
- No additional anchorage reinforcement
- No visible anchorages
- Rapid installation
- Reparable after a seismic action
Laboratory of Heavy Structures
DEC – FCT - UNL
Thank you for your attention!

Obrigada!

ありがとう！

Faleminderit!